

A MOTIONLESS LAMINOGRAPHY SYSTEM

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ABSTRACT

Thermal tiles developed by NASA Ames under the X37 program were inspected using Digiray®'s new Motionless Laminography System. It revealed void variations in internal layers of the tiles. This system was also used to inspect foam panels provided by Marshall Space Flight Center to help determine the cause of foam breaking loose from the Space Shuttle external tank. Delaminations were detected within the foam and at the tank attachment area. Determinations of specifications, applications, and advantages of the laminography system are presented.

1. INTRODUCTION

Digiray® has developed and marketed a motionless laminography system. It uses a reverse geometry scanning x-ray source and an array of 64 small detectors. The system generates a sequence of laminographic slices which may be reconstructed to produce three-dimensional x-ray images.

Fig. 1 illustrates the Digiray (Reverse Geometry X-ray)® and (RGX)® concept. The reverse geometry shows the object close to the source instead of close to the detector as in conventional systems. The result is that most of the scattered x-rays are not detected by the system. The single detector may be replaced by an array of detectors which are simultaneously exposed to x-rays of the object shown in Fig. 2.

The diagram in Figure 2 shows the x-ray source on the left. A scanning beam generated in a raster pattern using a magnetically deflected electron beam inside the x-ray tube produces X-rays. The fan beam is then transmitted through a thin anode window and the adjacent object. When these x-rays impinge on the detectors they produce an output signal which enters an amplifier. An analog-to-digital converter digitizes the amplifier's output. The resulting digitized signals are then synchronized with the raster pattern generated in the x-ray tube and stored in the computer memory. The result is a two dimensional pattern of picture elements associated with each detector in the array. The patterns are shifted and added together to create a layer-by-layer view of the object.

The photos in the upper part of Fig. 2 show the difference between a transmission x-ray on the left and laminography on the right. Using laminography, the two sides of a U.S. quarter are shown with the image of the head separated from the image of the tail.

2. APPLICATIONS AND RESULTS

We will now discuss some of the x-ray results obtained for spatial resolution acquired for laminography slices. These results are compared to transmission x-ray resolutions measured on the same sample under the same conditions. A plastic (lucite) wedge is shown in Fig. 3 which is made up of seven steps ranging from one inch to 4 inches. A four-hole penetrameter is mounted on each step with holes ranging from (0.5T to 2T) or (1% to 4%) change in density compared to the total density of each step. Each hole is visible on all seven steps.

On the left side of this figure is an x-ray of an identical seven-step wedge on which are mounted penetrameters containing the same size holes (0.5T to 2T). These holes are difficult to discern; they are not very clear. The clarity of the penetrameters on the right wedge is much better. Laminography greatly improved the resolution.

To indicate the resolution of the laminography system we x-rayed a gold wire with a diameter of 12.5 microns, which was the smallest diameter object available to us. The wire laminograph shown in Fig. 4 is clearly resolved indicating the system resolution is better than 12.5 microns. The extreme contrast sensitivity of the system is also indicated by the detection of a piece of scotch tape having a thickness of 1 mil also shown in Fig. 4.

Figure 5 shows a model of the Columbia Space Shuttle leading edge. It was impacted with a piece of foam about the size of the foam that broke off the space shuttle, which caused it to crash. This was done to simulate the Columbia accident. Boeing provided the model of the leading edge and Digiray performed the laminography under a Boeing contract.

Figure 6 shows two laminographs of the leading edge and the result of the crack penetrating from the outside to the inside of the leading edge. We created a movie of the entire progression of this crack as it traveled through the thickness of the leading edge from one side to the other. Here we display only the slices at the entrance and exit of the leading edge.

Figure 7 shows a photo of a 2.5-inch thick yoke portion of a CH-47 helicopter blade which was provided by Boeing Helicopter. To its right is a laminography slice of it near its surface. The cross pattern of the ¼ inch-wrapping weave is indicated in this laminography slice.

Figure 8 shows two more laminographs at indicated depths beneath the surface of the yoke. At these depths the weave has a very different pattern from the cross-weave pattern shown in Figure 7 and has become linear. Its distorted curvature could cause a weakening of the yoke's strength.

Figure 9 is a foam sample provided by James L. Walker of Marshall Space Flight Center. This is a copy of the foam insulation wrapping the Space Shuttle External Tank. Using laminography we detected all of the manufactured delaminations in its interior. Figure 9 is a laminograph showing two of the delaminations in the adhesive layer that bonds the foam to the aluminum substrate.

Figure 10 is a comparison between transmission and laminography x-rays for a sample of aluminum honeycomb. This x-ray reveals three important benefits of laminography compared to

transmission x-rays; (1) the resolution of the laminography is considerably better (2) the field of view is much larger for laminography since it is considerably less limited by parallax (an array of detectors has a larger field of view than a single detector). (3) The laminography slice can be selected to pass through and enhance a particular layer such as that showing corrosion in the skin of the honeycomb sandwich.

The four figures below show laminography slices of ceramic thermal protection tiles. These were acquired by Digiray's laminography system under contract to NASA Ames. NASA Ames was developing the tiles.

Figure 11 shows a laminography slice detecting a broken thermocouple inside one of the tiles.

Figure 12 shows a crack in one of the tiles resulting from environmental testing during its arcjet test.

Figure 13 shows an x-ray of an assemblage of experimental tile cubes having controlled density variations. The density was controlled by varying the amount of glass in the carbonaceous fiberform matrix.

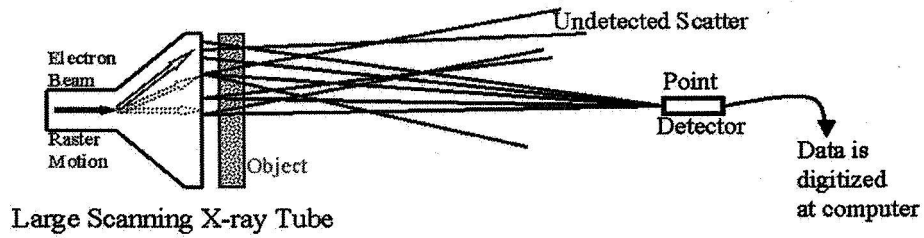
Figure 14 shows porosity variations acquired during a sequence of laminography slices through a sample of Rocci tile.

3. BENEFITS

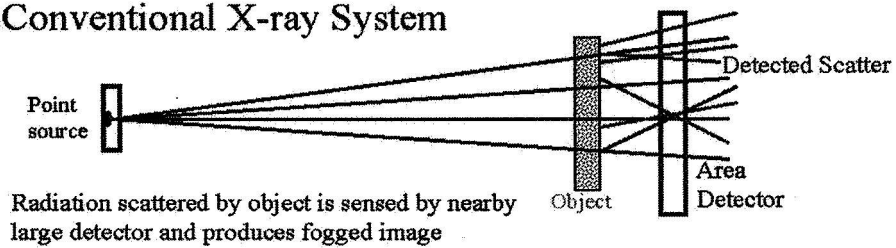
To sum up, the Digiray motionless laminography system has the following important benefits:

- *Inspects the interior of a specimen layer-by-layer. (See figure 2)*
- *Locates defects in each layer rapidly.*
- *Eliminates most x-ray scattering. (see figure 1).*
- *Shows much higher spatial resolution than transmission x-ray. (see figure 3)*
- *Widens the field of view by eliminating parallax. (see figure 10)*
- *Acquires up to a thousand eight-mil layers in one single short x-ray exposure.*
- *Contrast sensitivity is less than 0.1%.*
- *Contrast ratio is greater than 1500/1.*
- *Set-up is fast because close alignment between source and detector is not required.*

Reverse Geometry X-ray System



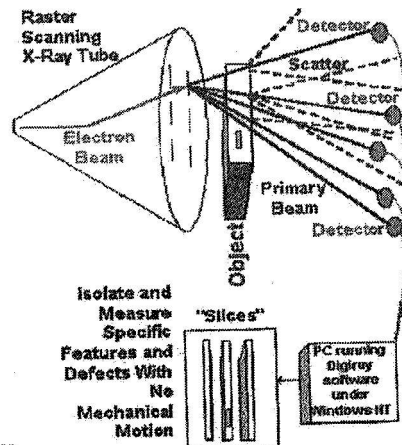
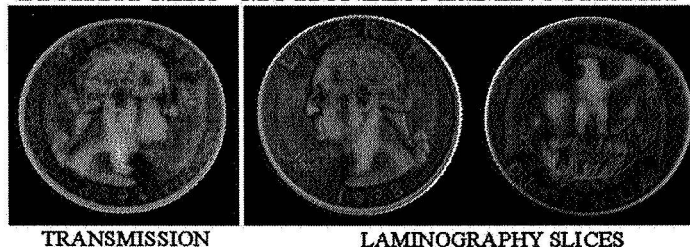
Conventional X-ray System



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FIGURE #1

DIGIRAY MLX™ MOTIONLESS LAMINOGRAPHY



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FIGURE #2

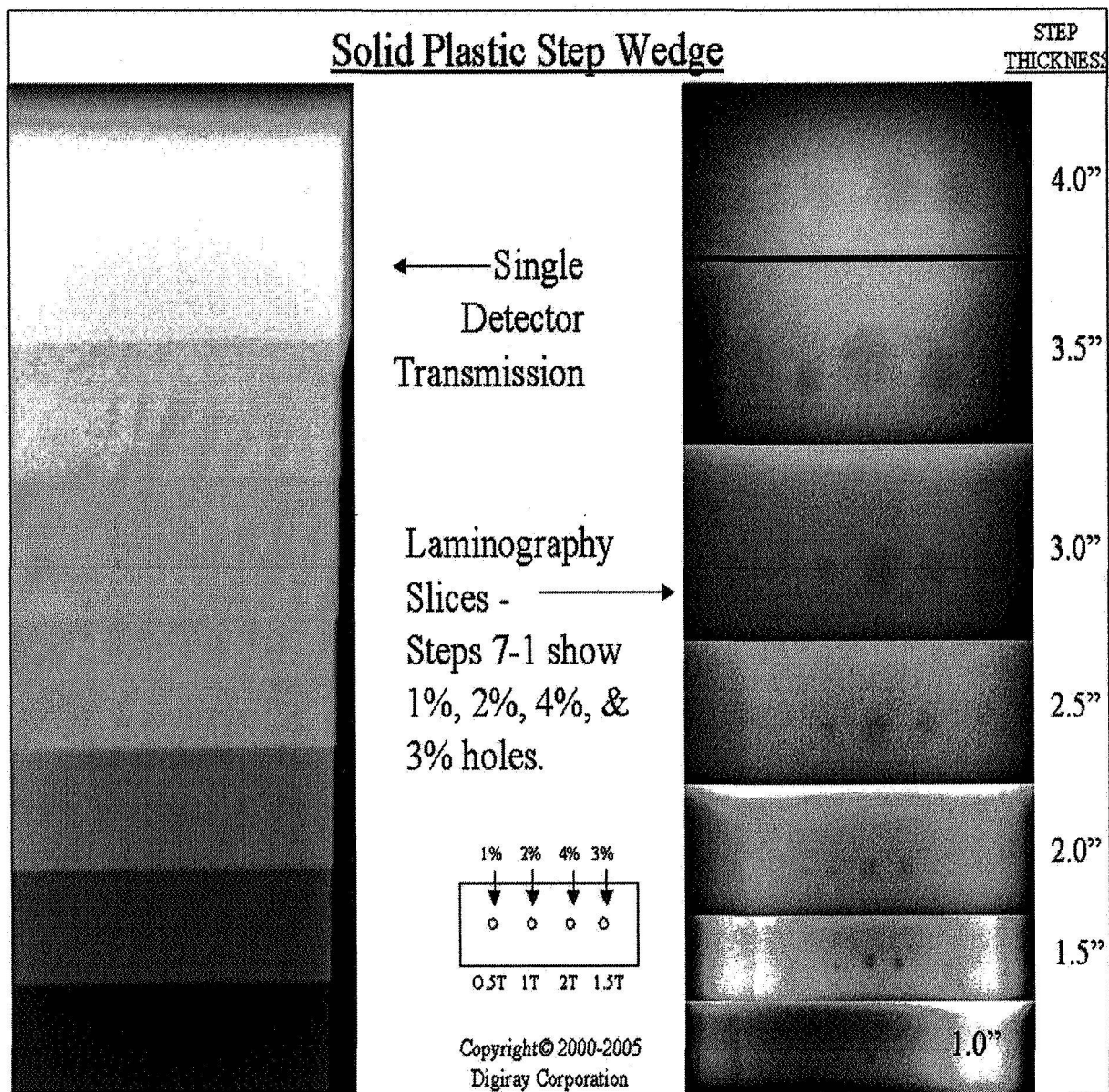


FIGURE #3

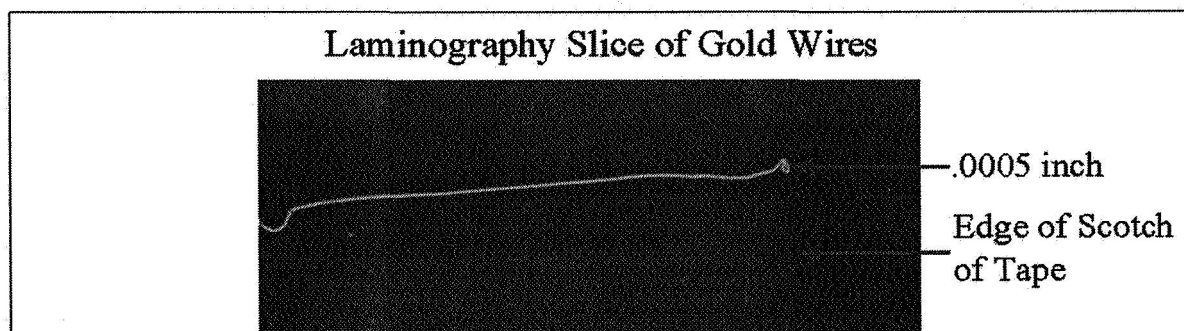
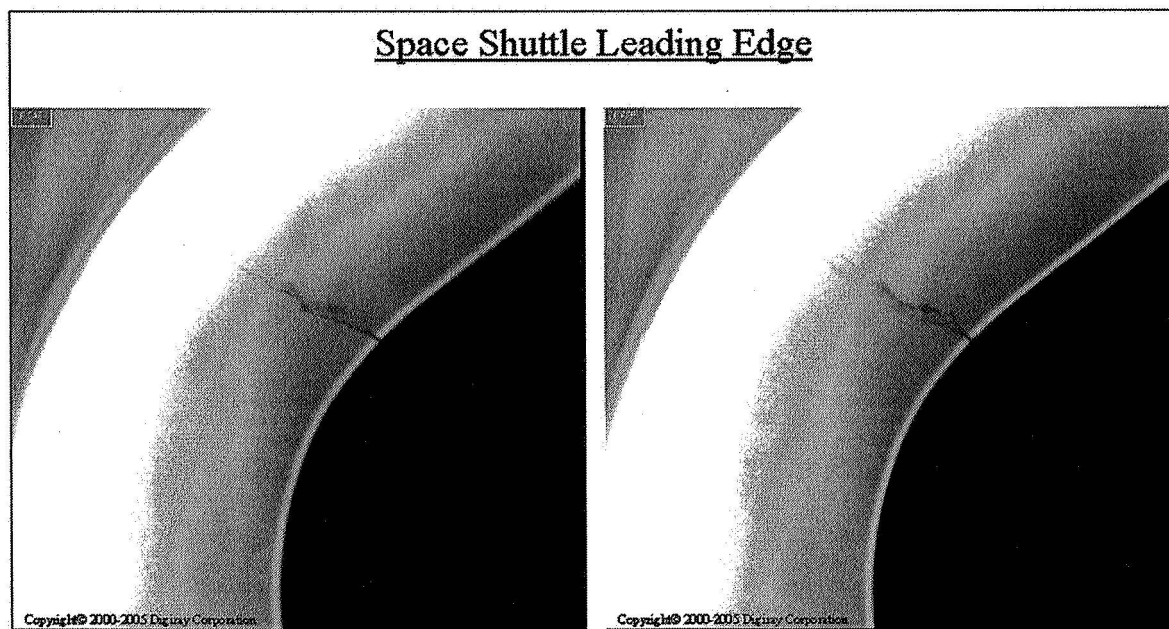
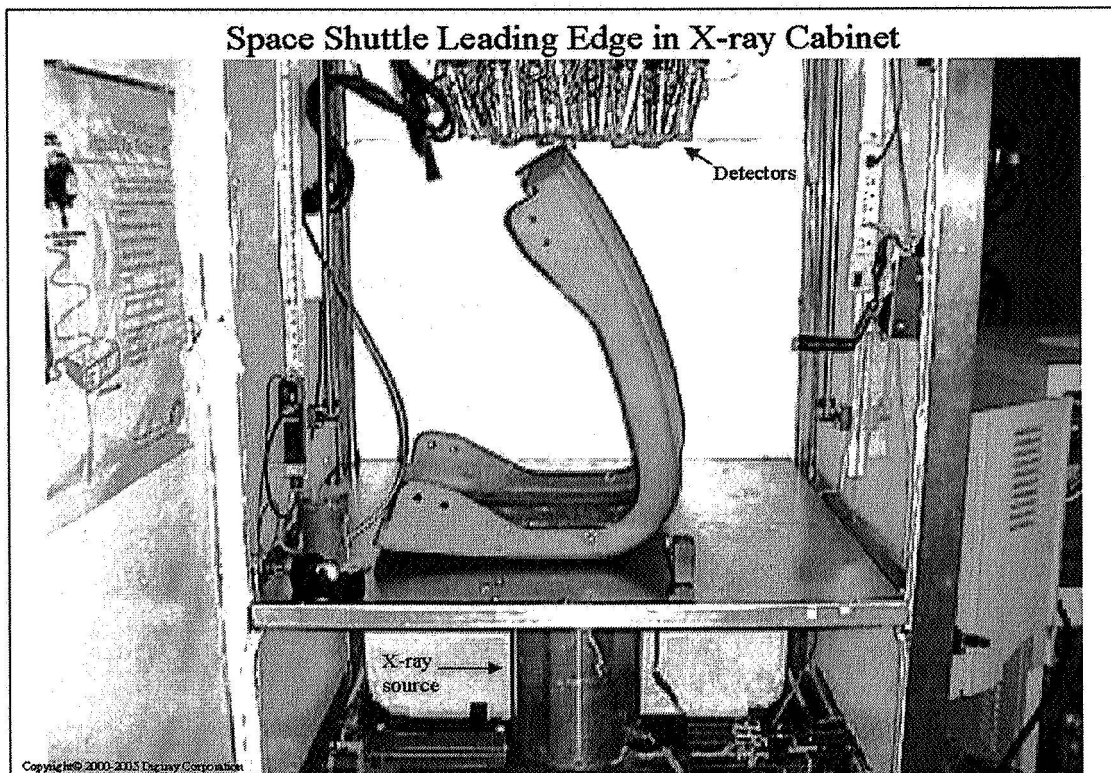


FIGURE #4



These are two laminography slices showing how a crack traveled from the outside to the inside of the shuttle's leading edge sample. The leading edge sample was supplied by Boeing of Huntington Beach and x-rayed by Digiray in July 2003 for part of the investigation of the Columbia shuttle crash.

Laminography Slices of a CH -47 Helicopter Yoke

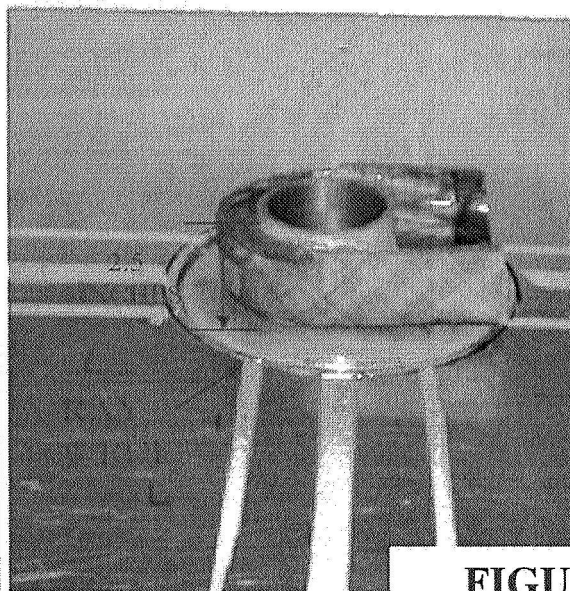
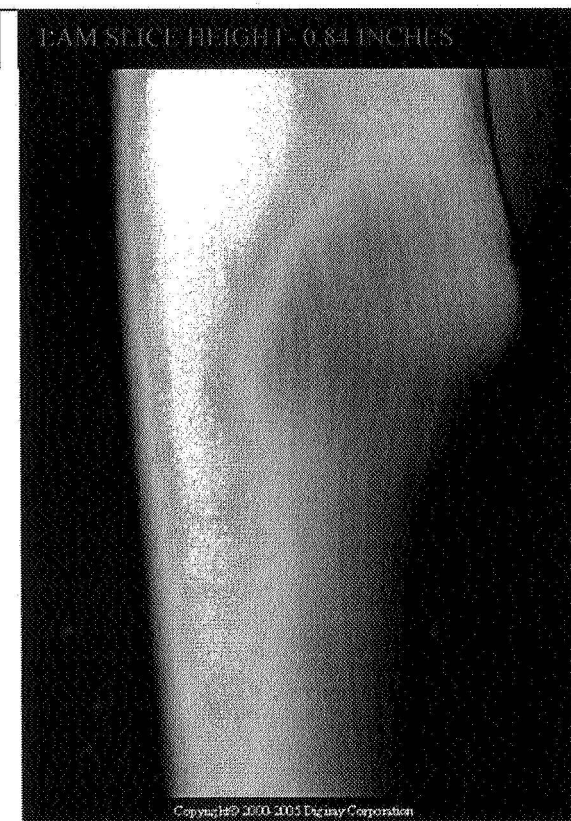


FIGURE #7



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FIGURE #8

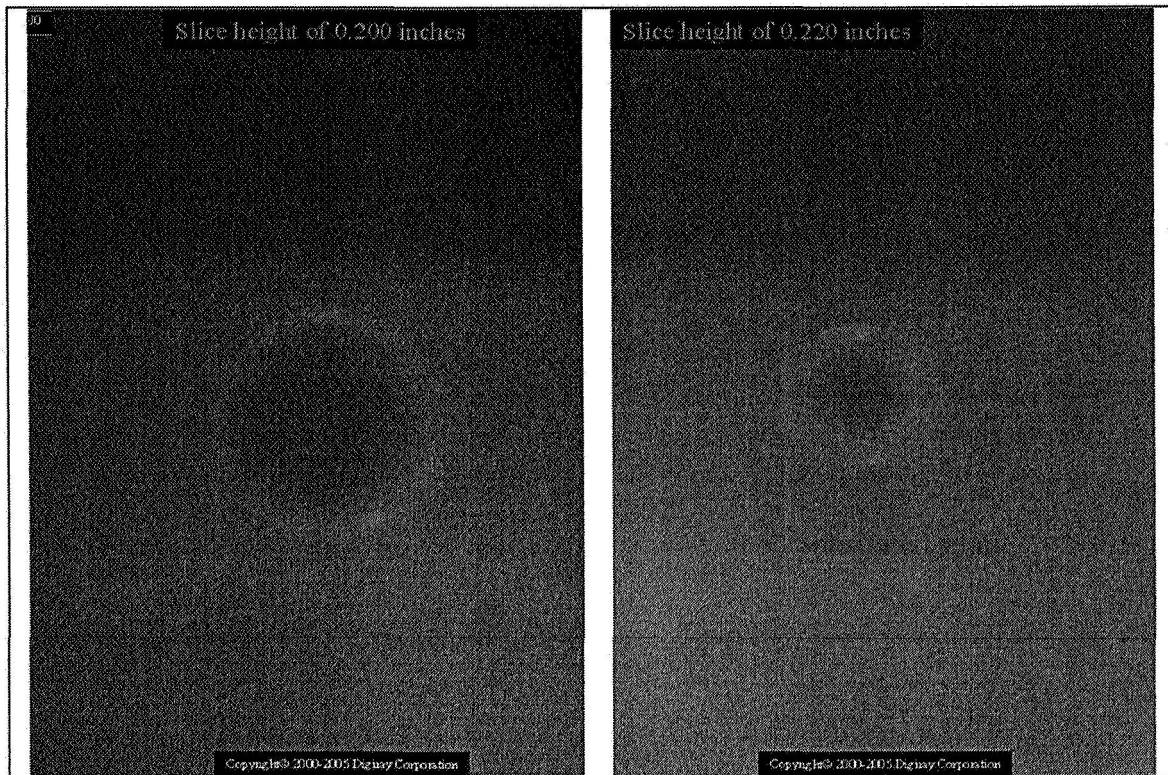


FIGURE #9

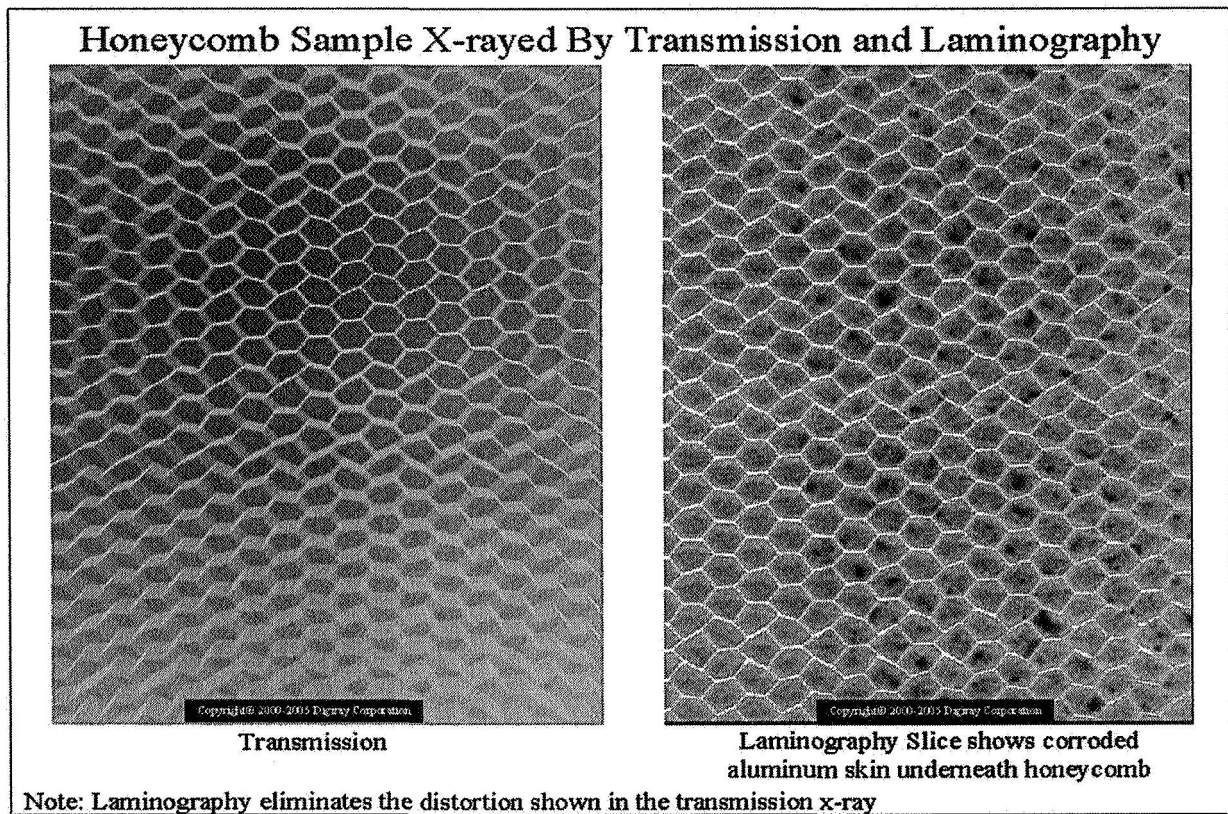
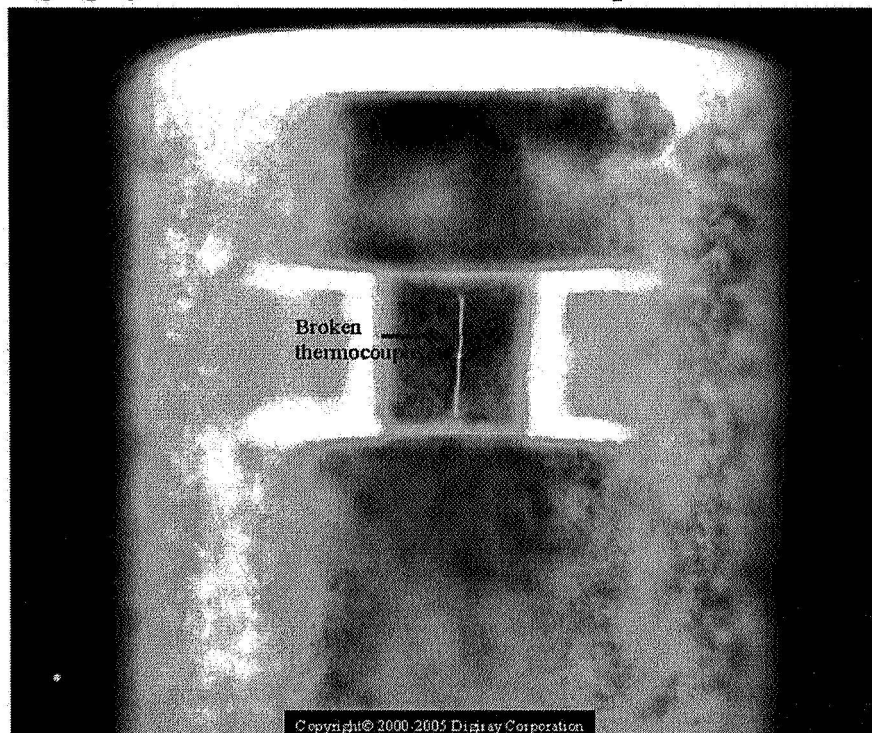


FIGURE #10

Laminography Slice of a Broken Thermocouple in a X37 TPS TILE



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FIGURE #11

Laminography slice of a crack in X-37 TPS tiles after arc jet tunnel test

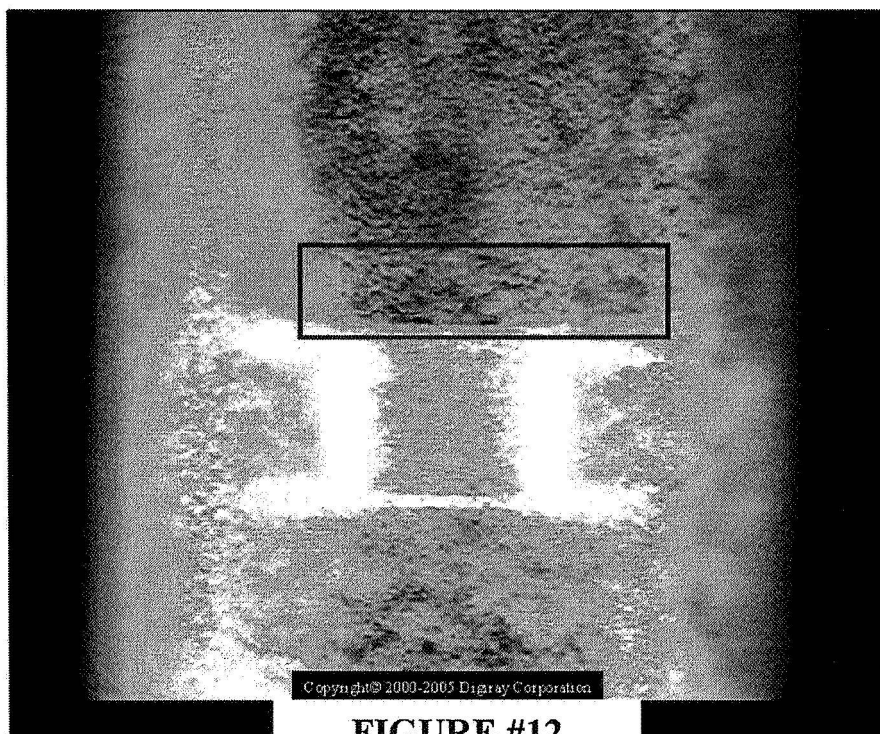
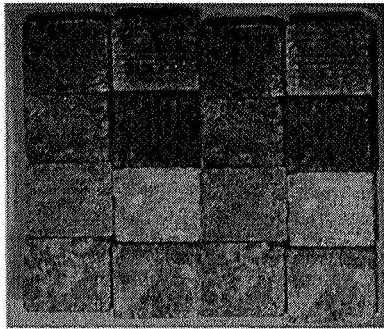


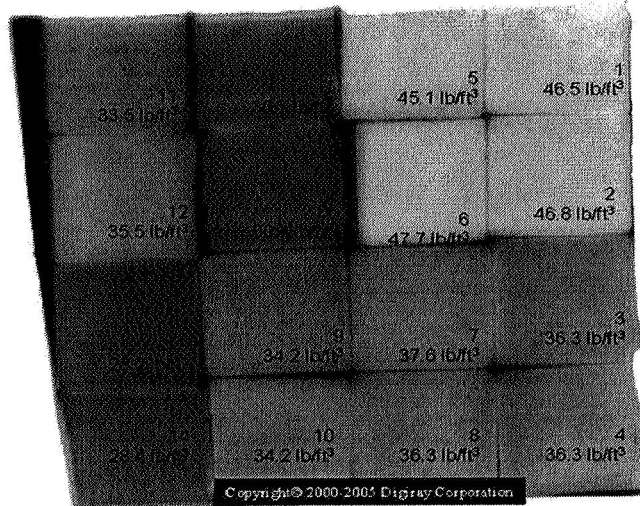
FIGURE #12

ROCCI density variation- experimental cubes

- By varying the amount of glass in the matrix, the density can be controlled
- Carbonaceous Fiberform remains constant for all samples



Representative Image only



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FIGURE #13

Provided by NASA Ames Research Center

Laminography Slices of X-37 Rocci Billet

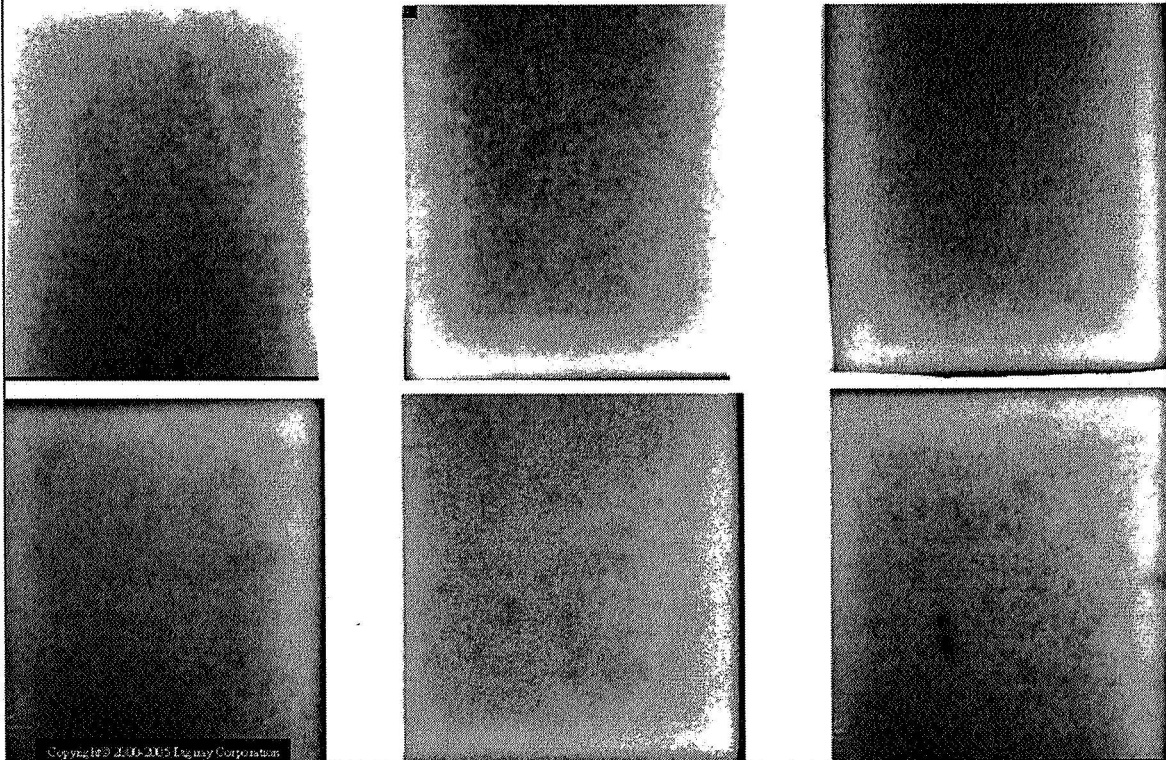


FIGURE #14